FAST TRACK ARTICLE

Food as a Source of Dioxin Exposure in the Residents of Bien Hoa City, Vietnam

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Recently, elevated dioxin levels, over 5 parts per trillion (ppt) 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), from Agent Orange was reported in 95% of 43 selected residents of Bien Hoa City, a city in southern Vietnam near a former air base used for Agent Orange-spraying missions. Agent Orange herbicide, contaminated with TCDD, was sprayed in Vietnam between 1962 and 1971 primarily for use as a defoliant. Typical blood TCCD levels are 2 ppt in Vietnamese, but levels are as high as 413 ppt in Bien Hoa City. Elevated TCDD was found in children born many years after Agent Orange spraying ended and in immigrants from non-Agent Orange-sprayed parts of Vietnam, which documented new exposures. Extremely elevated soil TCDD samples, over 1 million ppt, and elevated TCDD in sediment were found in some nearby areas such as Bien Hung Lake. The primary route of intake of almost all dioxins in humans is food. However, in our prior studies in Bien Hoa, food was unavailable for dioxin analysis so the route of intake was not confirmed. In the 1970s, while Agent Orange was still being sprayed, elevated human milk TCDD levels as high as 1850 were detected in milk from Vietnamese people living in Agent Orange-sprayed areas where consumption of fish was high. Furthermore, also in the 1970s, elevated TCDD levels (up to 810 ppt) were found in fish and shrimp from the same area as the milk donors. In the 1980s, we found elevated TCDD and also other organohalogen levels in human tissue, pork, fish, a turtle, and a snake in Southern Vietnam. For these reasons, we recently collected food from Bien Hoa and analyzed it for dioxins, polychlorinated biphenyls (PCBs), DDT and its metabolites, and other organochlorines. We found marked elevation of TCDD, the dioxin characteristic of Agent Orange, in some of the food products, including ducks with 276 ppt and 331 ppt wet weight, chickens from 0.031–15 ppt wet weight, fish from 0.063–65 ppt wet weight, and a toad with 56 ppt wet weight. Usual TCDD levels in food are less than 0.1 ppt. Total TEQ for ducks was from 286–343 ppt wet weight or 536 ppt and 550 ppt lipid; for chickens from 0.35–48 ppt wet weight or 0.95–74 ppt lipid, for fish from 0.19–66 ppt wet weight or 3.2 ppt and 15,349 ppt lipid, and the toad was 80 ppt wet weight and 11,765 ppt lipid. Interestingly, this study did not find elevated levels of TCDD in the pork and beef samples. Clearly, food, including duck, chicken, some fish, and a toad, appears responsible for elevated TCDD in residents of Bien Hoa City, even though the original Agent Orange contamination occurred 30–40 years before sampling. Elevated levels of PCBs and DDT and its metabolites were found in some food samples. Furthermore, measurable levels of hexachlorocyclohexanes (HCH) and hexachlorobenzene (HCB) were found in a wide range of measurable levels. All of the 11 dioxin-like PCBs measured and presented plus 6 dioxins in addition to TCDD and 10 dibenzofurans contributed to the total dioxin toxicity (TEQ). However, when elevated, TCDD frequently contributed most of the TEQ. Thirty-six congeners from 7 classes of chemicals were measured in each of the 16 specimens providing a total of 576 congener levels. (J Occup Environ Med. *2003;45:781–788*)

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Agent Orange, a phenoxyherbicide mixture of 50% 2,4-dichlorophenoxyacetic acid (2,4-D) and 50% 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), was used during the Vietnam war by the U.S. military to defoliate jungles where enemy troops could hide and to destroy food crops. The herbicide was contaminated by the most toxic of the chlorinated dioxins, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD or TCDD). A substantial leak of over 5000 gallons of Agent Orange occurred underground at the Bien Hoa air base approximately 30 years before our sampling. Agent Orange spray records of the Air Force fixed-wing aircraft "Ranch Hand" group indicates that 42.6 million liters of Agent Orange out of 72.35 million liters of herbicide used was sprayed over 15% of the south of Vietnam in certain locations. Army helicopter, backpack, and naval spraying records are not readily available to help estimate the location and amounts of additional spraying [1,2]

Markedly elevated TCDD levels were found during the 1970s in some Vietnamese nursing mothers' milk and also fish from areas heavily sprayed with Agent Orange. TCDD levels were as high as 1850 parts per trillion (ppt) lipid in nursing mothers' milk and 810 ppt wet weight in fish.[3,4] Analyses performed during the 1980s and 1990s of over 2200 Vietnamese human tissue and blood, as well as a few wildlife samples for TCDD and other dioxins found several geographic locations where

TCDD, but not other dioxins, was elevated.[5–8] However, elevation of other organochlorines in some Vietnamese people was also noted.[7,9] The pattern of TCDD elevation is characteristic of dioxin exposure from Agent Orange. Other findings showed elevated TCDD in a turtle and a snake, and other food sometimes showed elevation of TCDD, in pork fat, fish, and chicken.[5,6,10] A similar finding but with smaller elevation of TCDD in humans, food, and soil was recently reported from the Aloui Valley of the Central Vietnam Mountains.[11–13] However, exported Vietnamese food purchased in the United States between 2000 and 2002 did not have detectable elevation of TCDD or other dioxins.[14] This was expected because most of Vietnam was not sprayed with Agent Orange, only certain locations in the south.

Bien Hoa City, a dioxin "hot spot," as contaminated areas have sometimes been referred to because of their high dioxin levels, is located approximately 32 km north of Ho Chi Minh City, formerly Saigon. During the past 5 years, some residents of Bien Hoa City were extensively tested for blood dioxin levels[15,16] Approximately 95% of blood samples taken from 43 selected persons were found to have elevated TCDD levels, above 5 ppt. These levels are greater than TCDD levels of less than 2 ppt reported in 3 individual samples and one pooled sample ($n = 100$) from North Vietnam. After the spraying of Agent Orange ended in 1971, the highest blood TCDD level found in Vietnam was 413 ppt, which was recently measured in a Vietnamese person living in Bien Hoa City. Children born after the spraying of Agent Orange ended, including 4 born during the 1980s, and those who recently moved to Bien Hoa, also had elevated TCDD levels. Some soil samples had elevated TCDD, including the highest measured to date in Vietnam of over 1 million ppt dry weight, but the majority of soil samples from Bien Hoa and elsewhere had TCDD below detection limits. In the vicinity of Bien Hoa City, soil and sediment samples from the Bien Hung Lake showed areas with elevated TCDD, while other samples from the same body of water and other nearby areas, including lakes and rivers, did not.[15] The purpose of this study was to determine if food is the route of current intake of TCDD into persons living in Vietnamese "hot spots."

Methods

The food for this study was collected in 2002 from the Bien Hoa market, the Bien Hung market, the Bien Hung Lake, and at the nearby air base where Agent Orange was stored. All are within several kilometers of each other.

Sixteen food samples were collected of free-ranging and cooped chickens, free-ranging ducks, pork, beef, fish, and a toad. The free-ranging or "unbridled" chickens and ducks had the opportunity to roam and consume food from a relatively wide area compared with the cooped animals. Because fat is a delicacy in Vietnam, fat attached to flesh was sampled when possible. The food samples were frozen and then shipped frozen (on dry ice) from Vietnam to Hamburg, Germany, for analysis of selected persistent organic pollutants, the carcinogenic dioxins, dibenzofurans, PCBs, and other toxic chemicals. The uncooked food, muscle with fat, was homogenized and then analyzed. The entire toad was homogenized prior to analysis. The analytical methods for dioxins, which include high-resolution gas chromatography-high resolution mass spectrometry (HRGC/HRMS), which produce congener-specific results for low parts per trillion levels, have previously been described and are not repeated here.[17] ERGO Research Laboratory has successfully participated in various interlaboratory validation tests and is certified for dioxin, dibenzofuran, and PCB analysis in various human tissues by the World Health Organization (WHO).[18] Three of the samples were analyzed in a second WHO-approved laboratory in Freiburg, Germany to confirm the high levels of TCDD found in the ERGO laboratory.

Results

The results of the recent food analysis from Bien Hoa are presented in 7 tables and 1 figure. Tables 1 and 2 show dioxin, dibenzofuran, and PCB levels and total dioxin toxic equivalents (TEQ), a measure of total dioxin toxicity not only from TCDD, but also from other dioxins, dibenzofurans, and dioxin-like PCBs, of the 16 food samples from Bien Hoa. Tables 3 and 4 show the levels of hexachlorocyclohexanes (HCH), hexachlorobenzene (HCB), as well as DDT and its metabolites. Table 5 presents TCDD and total dioxin toxic equivalents as well as percent of the total TEQ from TCDD in each specimen. Table 6 presents the food data in TEQs on a wet weight and lipid basis. Table 7 compares the environmental and human data from Bien Hoa to that of Aloui Valley, another dioxin "hot spot," which was recently published.[11–13] Figure 1 presents the new food data in a graphic format for ease of visualization.

It can be noted in Tables 1 and 2 that TCDD, the dioxin characteristic of Agent Orange, varies on a wet weight basis from a low of 0.025 ppt in a pork sample to a high of 331 ppt in a duck, a 13,240-fold range. Total dioxin toxic equivalents vary from 0.11 ppt in the beef sample to 343 ppt in a duck, a 3118-fold difference. This finding is similar to that of a previous Vietnam investigation that found duck fat to be the food highest in TCDD[11–13] The 2 highest TCDD values, 276 ppt and 331 ppt, were found in free-ranging ducks. The fish *Channa striata* or snakehead, caught from the contaminated Bien Hung Lake, had the highest fish TCDD level and the third highest level of all food samples, 65 ppt. This fish sur-

TABLE 1
Dioxin, Dibenzofuran, and PCBs, in Food From Bien Hoa City, Vietnam (pg/g or ppt wet weight)

	Fish 1	Fish 2	Fish 3	Fish 4	Fish 5	Duck 1	Duck 2	Toad
Fat content (%)	0.43	1.1	41	4.0	1.8	52	64	0.68
2.3.7.8-TCDD	65	0.13	0.22	0.062	0.38	276	331	56
1.2.3.7.8-PnCDD	0.80	0.011	0.24	0.028	0.051	6.4	7.4	9.3
1.2.3.4.7.8-HxCDD	0.098	ND (0.01)	0.10	0.021	0.017	1.0	1.1	9.4
1.2.3.6.7.8-HxCDD	0.27	ND (0.008)	0.28	0.044	0.050	1.9	2.2	39
1.2.3.7.8.9-HxCDD	0.079	ND (0.007)	0.11	0.016	0.017	0.43	0.48	1.6
1.2.3.4.6.7.8-HpCDD	0.59	ND (0.03)	0.37	0.079	0.077	2.7	3.0	19
OCDD	0.96	ND (0.2)	0.47	ND (0.2)	0.14	3.7	4.1	13
2.3.7.8-TCDF	0.60	0.044	1.2	0.47	0.12	17	21	0.083
1.2.3.7.8-PnCDF	0.057	ND (0.004)	0.35	0.095	0.043	0.48	0.56	0.17
2.3.4.7.8-PnCDF	0.093	0.0077	0.24	0.053	0.041	0.90	1.1	5.2
1.2.3.4.7.8-HxCDF	0.072	ND (0.005)	0.17	0.029	0.026	1.2	1.5	8.8
1.2.3.6.7.8-HxCDF	0.022	ND (0.004)	0.092	0.0090	0.0076	0.49	0.47	2.1
1.2.3.7.8.9-HxCDF	ND (0.01)	ND (0.008)	ND (0.02)	ND (0.01)	ND (0.004)	0.045	0.056	0.11
2.3.4.6.7.8-HxCDF	0.014	ND (0.007)	0.036	ND (0.01)	ND (0.01)	0.13	0.16	0.91
1.2.3.4.6.7.8-HpCDF	0.016	0.017	ND (0.04)	ND (0.02)	ND (0.02)	0.53	0.43	0.62
1.2.3.4.7.8.9-HpCDF	ND (0.01)	ND (0.001)	ND (0.03)	ND (0.01)	ND (0.004)	0.21	0.25	0.089
OCDF	ND (0.04)	0.098	ND (0.06)	ND (0.02)	ND (0.03)	0.23	0.19	0.27
PCB 81	0.16	0.078	0.71	0.13	0.18	2.0	2.3	3.0
PCB 77	2.7	2.0	12	ND (1)	5.0	53	58	2.1
PCB 126	2.7	0.25	3.7	0.32	0.88	9.5	11	51
PCB 169	0.25	ND (0.05)	1.3	0.079	0.12	1.6	1.8	6.6
PCB 105	143	14	116	28	32	397	490	310
PCB 114	7.6	ND (0.5)	ND (8)	2.1	1.4	ND (17)	ND (12)	33
PCB 118	261	28	306	91	73	912	967	4023
PCB 156	54	3.7	36	7.6	12	156	161	1005
PCB 157	14	ND (0.8)	ND (15)	ND (1)	3.3	57	22	295
PCB 167	20	1.9	22	4.1	5.7	70	47	617
PCB 189	4.5	ND (1)	ND (18)	ND (2)	ND (1)	ND (21)	ND (17)	146
TEQ PCDD/PCDF	66	0.16	0.81	0.18	0.48	285	341	74
TEQ non-ortho PCB	0.28	0.026	0.38	0.033	0.090	0.97	1.1	5.2
TEQ mono-ortho PCB	0.079	0.0068	0.074	0.017	0.019	0.25	0.25	1.1
SUM TEQ	66	0.19	1.3	0.23	0.59	286	343	80

Fish 1: *Channa Striata*—snakehead.
Fish 2: *Anabas Testudineus*—climbing perch.
Fish 3: *Clarias Fuscus*—catfish.
Fish 4: *Clarias Fuscus*—catfish.
Fish 5: *Ostechilus Hasselti*—carp.
ND—nondetected, limit of detection in brackets.

vives the dry season by burrowing in the bottom of lakes and subsisting on stored fat. The toad had the fourth highest level of TCDD, 56 ppt, and a free-ranging chicken the fifth highest level, 15 ppt. In this series, only 1 of 5 fish sampled had elevated TCDD, despite 3 of the 5 having come from the contaminated Bien Hung Lake. Penta-CDD is also elevated in some samples of chicken, duck, and the toad.

PCBs are sometimes quite elevated, as is the case for the 2 free-ranging chickens (1 and 4; 14.9 and 8.5 ppt, respectively) and the toad (6.3 ppt). In Tables 3 and 4, it can be noted that α-HCH varies from 2.3–129 ppt, a 56-fold range. β-HCH varied from 3.0–846 ppt, a 282-fold range. γ-HCH varies from 0.76–215 ppt, a 283-fold range. Hexachlorobenzene varies from not detected with a detection limit of 4 up to 1391 ppt, a 696-fold range. DDT and its metabolites vary considerably: op-DDT from 1.9–629 ppt, a 331-fold range; pp-DDT from 46–44,722 ppt, a 972-fold range; pp-DDE from 305–149,409 ppt, a 490-fold range; and pp-DDD from 103-6513 ppt, a 63-fold range. Elevations are noted for many of these persistent organochlorines, and an extremely wide variation exists for dioxins, PCBs, DDT and metabolites, and also HCHs and HCB. Table 5 shows TCDD's contribution to the total TEQ fluctuates from 3.7–98.5% of the total TEQ. The TCDD range in fish is from 16.9–98.5% of the total TEQ and in chickens from 3.7–31.3% of the total TEQ. Pork varied from 4.2–78% of the total TEQ from TCDD. Table 6 shows that the total TEQ on a lipid basis varies from 0.94 ppt in pork to 15,349 ppt in the fish, *Channa striata* or snakehead, the fish with the highest concentration of TCDD. Table 7 compares levels for TEQ on a wet weight basis for similar samples

TABLE 2
Dioxin, Dibenzofuran, and PCBs, in Food Samples From Bien Hoa City, Vietnam (pg/g or ppt wet weight)

	Pork 1	Pork 2	Beef 1	Beef 2	Chicken 1	Chicken 2	Chicken 3	Chicken 4
Fat content (%)	52	64	3.3	12	65	29	37	38
2.3.7.8-TCDD	0.86	0.025	0.082	0.082	15	0.031	0.034	7.3
1.2.3.7.8-PnCDD	ND (0.02)	0.049	0.0060	0.039	8.5	0.088	0.055	4.8
1.2.3.4.7.8-HxCDD	ND (0.02)	0.14	0.0029	0.013	8.2	0.14	0.056	4.7
1.2.3.6.7.8-HxCDD	ND (0.01)	0.19	0.0067	0.058	38	0.35	0.19	22
1.2.3.7.8.9-HxCDD	ND (0.01)	0.027	0.0037	0.021	4.7	0.12	0.038	2.5
1.2.3.4.6.7.8-HpCDD	0.068	0.78	0.023	0.093	63	0.56	1.1	36
OCDD	0.39	1.1	0.10	0.55	122	0.38	2.6	96
2.3.7.8-TCDF	0.078	ND (0.05)	0.012	0.016	4.7	0.21	0.084	2.5
1.2.3.7.8-PnCDF	ND (0.01)	ND (0.02)	0.0035	0.0072	4.6	0.32	0.045	2.6
2.3.4.7.8-PnCDF	0.018	0.11	0.0062	0.034	4.4	0.16	0.039	2.3
1.2.3.4.7.8-HxCDF	0.018	1.8	0.0051	0.020	5.7	1.9	0.069	3.0
1.2.3.6.7.8-HxCDF	ND (0.01)	0.60	0.0026	0.012	2.5	0.98	0.038	1.4
1.2.3.7.8.9-HxCDF	ND (0.02)	ND (0.03)	ND (0.001)	ND (0.005)	0.32	0.12	ND (0.02)	0.18
2.3.4.6.7.8-HxCDF	ND (0.02)	0.068	ND (0.004)	ND (0.006)	1.4	0.18	ND (0.05)	0.82
1.2.3.4.6.7.8-HpCDF	ND (0.04)	2.5	0.012	0.033	3.5	1.5	0.13	1.8
1.2.3.4.7.8.9-HpCDF	ND (0.02)	1.1	ND (0.001)	ND (0.007)	0.34	0.99	ND (0.02)	0.17
OCDF	ND (0.06)	0.93	0.0099	0.039	1.5	1.00	0.11	0.74
PCB 81	ND (0.1)	ND (0.2)	ND (0.02)	ND (0.06)	19	ND (0.4)	ND (0.3)	11
PCB 77	ND (5)	ND (5)	ND (0.6)	ND (1)	145	ND (10)	ND (9)	78
PCB 126	ND (0.9)	ND (0.9)	ND (0.10)	0.40	108	ND (2)	ND (1)	62
PCB 169	0.15	0.34	0.027	0.15	8.2	ND (0.2)	ND (0.2)	4.5
PCB 105	100	92	ND (6)	ND (13)	7189	ND (50)	ND (75)	3847
PCB 114	ND (13)	ND (11)	ND (1.0)	ND (2)	318	ND (4)	ND (9)	241
PCB 118	369	176	17	ND (38)	14182	ND (154)	ND (192)	8216
PCB 156	113	ND (5)	2.3	ND (1)	2461	9.9	10	1520
PCB 157	24	ND (18)	ND (0.9)	ND (3)	603	ND (5)	ND (7)	292
PCB 167	51	26	ND (0.3)	ND (0.8)	1076	ND (5)	9.4	539
PCB 189	30	ND (18)	ND (1)	ND (6)	176	ND (10)	ND (11)	133
TEQ PCDD/PCDF	0.91	0.46	0.095	0.16	33	0.64	0.18	17
TEQ non-ortho PCB	0.089	0.096	0.010	0.042	11	0.16	0.13	6.2
TEQ mono-ortho PCB	0.13	0.046	0.0045	0.0088	3.9	0.031	0.041	2.3
SUM TEQ	1.1	0.60	0.11	0.21	48	0.83	0.35	26

ND—nondetected, limit of detection in brackets.

TABLE 3
Organochlorine Pesticides in Food Samples From Bien Hoa City, Vietnam (pg/g or ppt wet weight)

	Fish 1	Fish 2	Fish 3	Fish 4	Fish 5	Duck 1	Duck 2	Toad
Fat content (%)	0.43	1.1	41	4.0	1.8	52	64	0.68
α-HCH	2.3	11	78	6.0	17	8.7	28	2.4
β-HCH	3.0	4.7	114	9.7	8.3	351	418	87
γ-HCH	3.3	5.6	46	0.76	7.5	25	64	5.3
Hexachlorbenzene	563	ND (32)	231	ND (4)	ND (15)	1145	1391	129
Pp′-DDD	358	338	2596	403	594	4322	5605	969
Op′-DDT	1.9	9.8	233	69	4.6	42	48	36
Pp′-DDT	179	118	2368	709	96	23468	26823	6115
Pp′-DDE	4989	305	8141	613	671	55342	68099	8003

Fish 1: *Channa Striata*—snakehead.
Fish 2: *Anabas Testudineus*—climbing perch.
Fish 3: *Clarias Fuscus*—catfish.
Fish 4: *Clarias Fuscus*—catfish.
Fish 5: *Ostechilus Hasselti*—carp.
ND—nondetected, limit of detection in brackets.

from 2 hot spots, Aloui Valley and Bien Hoa.[12,13,15,16] Usually, but not always, TEQ values are far higher in Bien Hoa, documenting to variations in dioxin levels in different "hot spots." Figure 1 presents the food samples in a visual form with TEQs from PCBs, PCDD/Fs and TCDD on each bar of the graph.

TABLE 4
Organochlorine Pesticides in Food Samples From Bien Hoa City, Vietnam (pg/g or ppt wet weight)

	Pork 1	Pork 2	Beef 1	Beef 2	Chicken 1	Chicken 2	Chicken 3	Chicken 4
Fat content (%)	52	64	3.3	12	65	29	37	38
α-HCH	29	32	38	20	48	129	91	17
β-HCH	78	98	69	14	846	202	139	464
γ-HCH	39	40	20	20	25	215	115	1.2
Hexachlorbenzene	ND (790)	ND (1001)	ND (21)	ND (165)	ND (687)	ND (1708)	ND (1537)	ND (1294)
pp′-DDD	384	507	163	105	6513	103	1112	3463
op′-DDT	67	97	4.4	20	629	13	536	360
pp′-DDT	762	1717	46	71	44722	336	4203	26302
pp′-DDE	867	1261	575	643	149409	565	1303	85845

ND—nondetected, limit of detection in brackets.

TABLE 5
TCDD's Contribution of TCDD to Total TEQ of Food Samples From Bien Hoa City. (pg/g or ppt wet weight)

Samples	Measured TCDD	Total TEQ	TCDD percent of TEQ
Fish 1	65	66	98.5%
Fish 2	0.13	0.19	68.4%
Fish 3	0.22	1.3	16.9%
Fish 4	0.062	0.23	27.0%
Fish 5	0.38	0.59	64.4%
Duck 1	276	286	96.5%
Duck 2	331	343	96.5%
Toad	56	80	70.0%
Pork 1	0.86	1.1	78.2%
Pork 2	0.025	0.6	4.2%
Beef 1	0.082	0.11	74.5%
Beef 2	0.082	0.21	39.0%
Chicken 1	15	48	31.3%
Chicken 2	0.031	0.83	3.7%
Chicken 3	0.034	0.35	9.7%
Chicken 4	7.3	26	28.1%

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Fish 3: *Clarias Fuscus*—catfish.
Fish 4: *Clarias Fuscus*—catfish.
Fish 5: *Ostechilus Hasselti*—carp.

Discussion

This is the most recent Vietnam-U.S. collaborative dioxin research on food contamination, in a dioxin "hot spot" or heavily dioxin contaminated area, reported since 1990.[5,6] Moreover, this is the most recent research to document contamination of Vietnamese food, duck meat, chicken meat, fish, and a toad, with 7 classes and 36 congeners of toxic chemicals, including TCDD and other dioxins. These chemicals can cause an increased risk of cancer, immune deficiencies, reproductive and developmental changes, nervous system damage, liver injury, elevated blood lipids, skin damage, and death.[2] When studying human health in Vietnam, it seems reasonable from the data presented here to consider the presence of dioxins not only from Agent Orange and other sources, but also PCBs, HCH, HCB, and DDT and its metabolites. Although the spraying ended over 3 decades ago, in certain areas of Vietnam food is clearly a present-day route of intake of dioxin from Agent Orange, as it might have been since the spraying began in 1962.

In an area of Vietnam where recent TCDD exposure occurred and 95% of humans sampled had high blood levels, up to 413 ppt and a median of 67 ppt, markedly elevated TCDD levels were also found in 6 of 16 food samples.[16] In this study, free-ranging ducks, some chickens, as well as one bottom-dwelling fish and a toad from Bien Hoa City had elevated TCDD levels. The variation in TCDD levels in food from the same geographic area is striking. This variation was also found in human blood, sediment, and soil from the Bien Hoa area[15,16] Food, humans, sediment, and soil from Bien Hoa City show striking differences in levels of TCDD, despite taking samples from identical or nearby locations, which suggests problems in using environmental modeling approaches alone to estimate human exposure to Agent Orange and TCDD. Fixed-wing aircraft spray records have been recommended for exposure assessment of persons potentially exposed to Agent Orange with its TCDD contaminant rather than biologic measures such as congener-specific dioxin tissue analysis[19,20] When considering environmental model approaches to exposure assessment, it is necessary to note that TCDD has different bioavailability in different soil matrices, so the presence of TCDD alone does not necessarily correlate with the absorbed dose.[21] The findings of Vietnamese scientists Quynh, Dai, and Thom suggest that sometimes TCDD from Agent Orange in Vietnam can migrate from the originally sprayed areas. Wind, rain, and floods were

TABLE 6
A Comparison of Dioxin Toxic Equivalent in Food From Bien Hoa, Vietnam on a Wet Weight and Lipid Basis

Specimen	Total TEQ ppt wet weight	Percent lipid	Total TEQ ppt lipid
Fish 1	66	0.43	15,349
Fish 2	0.19	1.1	17
Fish 3	1.3	41	3.2
Fish 4	0.23	4	5.8
Fish 5	0.59	1.8	33
Duck 1	286	52	550
Duck 2	343	64	536
Toad	80	0.68	11,765
Pork 1	1.1	52	2.1
Pork 2	0.6	64	0.94
Beef 1	0.11	3.3	3.3
Beef 2	0.21	12	40
Chicken 1	48	65	74
Chicken 2	0.83	29	2.9
Chicken 3	0.35	37	0.95
Chicken 4	2.6	38	68

Fish 1: *Channa Striata*—snakehead.
Fish 2: *Anabas Testudineus*—climbing perch.
Fish 3: *Clarias Fuscus*—catfish.
Fish 4: *Clarias Fuscus*—catfish.
Fish 5: *Ostechilus Hasselti*—carp.

TABLE 7
Comparison of Highest Dioxin TEQ Levels in ppt, lipid, for the Aloui Valley, Vietnam, and Bien Hoa City, Vietnam

Aloui Valley[11–13]	Samples	Bien Hoa
85	Duck*	550
50	Fish*	15,349
5	Pork*	2.1
46	Human blood*	413
901	Soil†	1,100,000
35	Sediment†	190

* Lipid based TEQ.
† Dry weight TEQ.

hypothosized to be responsible for this.[22]

This study is the first to document current of TCDD from Agent Orange, sprayed 30–40 years previously, in food eaten by Vietnamese people. It is probable that consumption of food is responsible for elevation of TCDD levels in persons living near the Bien Hoa City dioxin "hot spot." This study also appears to be the first to find markedly elevated PCBs in some Vietnamese food samples. The source of this class of pollutants is unknown and has not previously been documented in Vietnam. Possible sources of PCBs include electrical transformers or capacitors and hydraulic fluid used during the Vietnam or Second Indochina war. For health reasons, these potential sources of food contamination need to be characterized and removed if feasible. When evaluating adverse health effects from Agent Orange, the presence of PCBs, additional dioxins and dibenzofurans, as well as TCDD must be considered. The PCBs measured in this study are dioxin-like and add to TCDD's toxicity. Others, by different mechanisms, could sometimes cause toxic end points similar or different from dioxins.[23,24] Total TEQ from polychlorinated dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), coplanar and mono-ortho PCBs (with dioxin-like TEQs) can raise the toxicity in many of these food samples significantly above that from TCDD alone, except where TCDD is extremely elevated. For these reasons, Agent Orange spray records alone do not necessarily reflect total dioxin-like toxicity measured in either Vietnamese people, Vietnamese food, or U.S. Vietnam veterans.[5,11–13,22] Biomonitoring, using congener-specific analysis of blood for dioxins and related compounds, markedly improves exposure assessment and is currently considered the "gold standard" for dioxin exposure by the U.S. Air Force, National Institute for Occupational Safety and Health (NIOSH), the Centers for Disease Control and Prevention (CDC), the states of New Jersey, Massachusetts, and Michigan, various universities, governmental agencies, Canadian researchers, and others.[11–13,25–33] The finding that TCDD levels in animals from this one geographic area varies by up to 13,240-fold is further evidence that biomonitoring is essential in determining the actual exposure or tissue dose. Spraying records, however, remain useful for identifying general areas of potential exposure.

Substitution of food not significantly contaminated with dioxins and other toxic chemicals is highly desirable for those Vietnamese people potentially exposed. In rare cases, environmental remediation, although expensive and slow, might also be an option. Additional health surveillance and care is indicated for exposed persons, especially in Vietnam. The findings of elevated levels of DDT and its metabolites and the varying levels of HCB and HCHs noted in this study can also contribute to adverse health outcomes with or without the presence of elevated dioxins[7,9] In Agent Orange studies of Vietnamese and Vietnam veterans from the United States or other countries, the adverse health consequences of these chemicals have not yet been taken into consideration. Public health work with a focus on dioxins and other chemicals needs to be continued and expanded for the sake of those for whom the etiologies of war connected pathology have been insufficiently characterized.

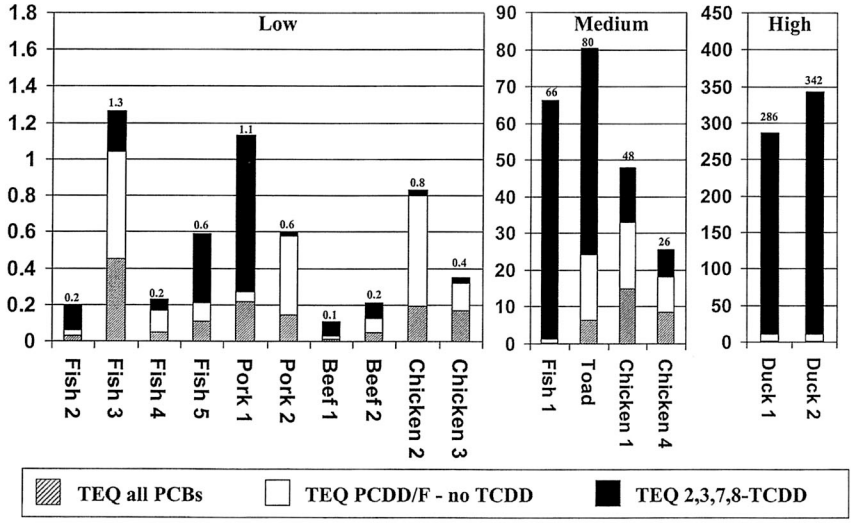

Fig. 1. TEQ contributions in food samples from Bien Hoa City, Vietnam in ppt, wet weight.

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